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Energy Demand and Carbon Emission Peak Paths for the Rise of Central China

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Abstract: The energy revolution is essential for the coordinated and sustainable development of economy, society, and environment; hence, it should coordinate with regional development strategies. In this study, we used the Kaya identity to categorize the energy demand triggered by the rise of Central China into production and living demand. Energy demand scenarios for this rise of Central China were established based on factors such as gross domestic product, industrial structure, urbanization, energy efficiency, per capita income, and residential energy. Based on these scenarios, the development of low-carbon pathways during the energy revolution was analyzed. In 2035, urbanization and industrialization were predicted to increase the total energy demand in the five provinces of Central China up to 8.4×10^8 –1.01×10^9 tce. Moreover, establishing a diversified energy supply system may contribute to achieving low carbon emissions, energy security, and the efficient utilization of energy; a carbon emission peak was anticipated prior to 2030. It is recommended that China invest significantly in developing clean, renewable energy and technologies for energy conservation. A complementary multi-energy system should be established in China by optimizing industrial structure since the existing system requires reform to realize energy cooperation between regions.

Keywords: energy revolution; rise of Central China; Kaya identity; scenario analysis; carbon emission peak

1 Introduction

Fossil fuel utilization provides the basis of power for economic and social development and generates pollutants such as sulfides, nitrides, inhalable particulate matter, and carbon dioxide (CO_2), which can cause environmental harm and contribute to global climate change. As such, the promotion of energy transformation has consistently been an area of intense concern in the international community [1–2]. Since 2006, China has become the country with the largest energy consumption and the highest CO_2 emissions. In 2019, coal consumption in China accounted for 51.7% of the global total, while its CO_2 emissions accounted for 28.8% of global emissions. China's coal-based energy structure is facing pressure from domestic and international communities to improve local environmental quality and reduce CO_2 emissions, respectively. China is also highly dependent on foreign oil and natural gas, and its energy security can be potentially threatened. Therefore, the sustainable and coordinated development of the energy, economy, and environment of China will require energy transformation and optimization of its energy structure.

China places significant importance on energy transition; the report from the 19th National Congress of the Communist Party of China proposed to revolutionize energy production and consumption and build a clean, low-carbon, safe, and efficient energy system [3–4]. Academic circles have carried out considerable research

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attempting to combine the strategic planning of energy development and the establishment of socialism with Chinese characteristics in the new era. For example, researchers have discussed the technologies needed, the development path, and the risk factors in the development of coal, renewable energy, and coalbed methane industries against the backdrop of an energy revolution [5–7]. This approach combines energy transition with the national conditions in China and follows an energy transition pathway with Chinese characteristics [8]. Studies have emphasized that energy supply and consumption reform and innovation are at the core of the energy revolution. These elements play an important role in promoting clean, low-carbon transitions, while other researchers postulate that to promote the reform of energy production and consumption, China should accelerate the reform of the energy price mechanism and energy systems as a way to improve the nation's energy system [9]. China spans a vast territory and there are substantial differences in the levels of energy endowment and development among regions, which is why the energy revolution must adapt to local conditions and combine it with a regional development strategy [10]. However, few studies have focused on combining the energy revolution and specific regional development strategies. For Central China, in particular, the level of industrialization and urbanization markedly differs from that of coastal areas, and the rise of Central China signifies greater and higher quality energy demand. In response to the national macro requirements [11], it is crucial to combine energy revolution strategies with the rise of Central China and research the potential for the energy revolution to promote high-quality development in the area.

The energy revolution boosting the rise of Central China is an improvement of economics and an overall improvement of the economy, society, and the natural environment. (1) Within economics, the energy revolution refers to ensuring the energy security of economic development in Central China and meeting the high-quality energy demand from this economic development. In terms of production input, technological progress should be actively used to rationally allocate energy, promote industrial transformation and upgrades, and improve energy efficiency. In terms of output, China should actively promote changes in the energy quality and power, and improve the former to reap its corresponding economic benefits. (2) Within society, the energy revolution should enable residents in Central China to experience a high quality of life and promote the transition from imbalanced and inadequate development to a harmonious society. The regional, urban–rural, and income gaps are an objective reality in economic development; these gaps are an important index representing the quality of life. As such, the energy consumption level should narrow the gap in eastern coastal areas and bridge the income gap between urban and rural residents. (3) Within ecology, the historical exploitation and application of resources in central regions have caused ecological damage and environmental pollution. The extent to which eco-efficiency, energy-saving, and emission-reduction technologies are implemented is also lower than that in the eastern regions [12]. The rising strategy for the central regions may aggravate the environmental pollution experienced by its cities [13]; hence, the energy revolution needs to rectify this situation. The high-quality development of the central regions requires the support of high-quality energy; the energy revolution should promote the coordinated development and quality improvement of the economic, social, and ecological dimensions in the central region (Fig. 1).

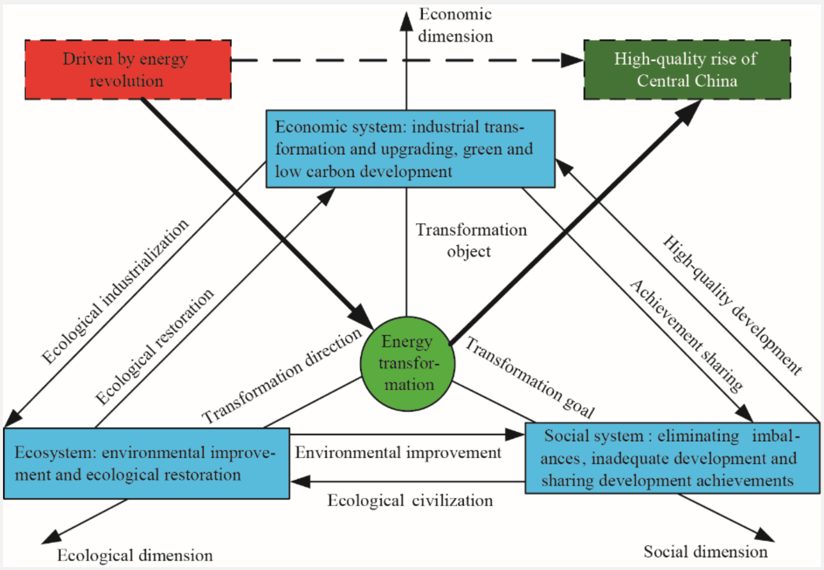

Fig. 1. Internal mechanisms of the energy revolution promoting the rise of high-quality development in Central China.

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This study attempts to connect the energy revolution strategy with the rise of the central region strategy. It consists of a preliminary discussion of the energy demand and path of the CO_2 emission peak during industrialization, urbanization, and modernization to provide a theoretical reference for energy development in Central China.

2 Energy demand prediction model for the rise of Central China

2.1 Energy demand modeling of industrialization and urbanization

Kaya identity uses a simple mathematical formula to describe the relationship between macro factors such as society, economy, energy, and carbon emissions. It is underpinned by a clear and concise principle—the decomposed driving factors are observable, controllable, and explanatory [14]. To capture energy characteristics in the regional economy, society, and environment, we divided demand of energy consumption into two parts: productive consumption and living consumption. The former corresponds to the energy demands of industry structure upgrades as part of the economic development of the central region— this is indicative of the energy revolution promoting the development of economics. The latter corresponds to demand from the optimization of urban and rural social structures during urbanization in the central region, which demonstrates that the energy revolution promotes progress within society. In addition, the reduction of the carbon content in energy represents the optimization of the energy structure and reflects the protection of the ecology via the energy revolution.

The reference adjustment equations in this paper are Equations (1)–(4), and the explanations of the relevant variables are shown in Table 1. Equation (1) examines the energy demand for industrialization and urbanization, while Equation (2) mainly uses the evolution law of industrial structure to represent the energy demands of different industrial developments. The middle variable of disposable per capita income is introduced in Equation (3), demonstrating that enhancing the per capita disposable income improves the quality of life and increases the energy demand. Finally, Equation (4) shows how clean and low-carbon energy quality can be used to calculate CO_2 emissions:

Table 1. Variable names and their design ideas or sources.

Variable	Name	Variable design ideas and sources
EI_{GDP}	Energy intensity	Ratio of energy consumption to gross domestic product
E_{P}	Energy consumption for production	Total energy consumption of primary, secondary, and tertiary industries
E_{R}	Energy consumption for living	Total urban and rural energy consumption
E_{PP}	Energy consumption of primary industry	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
E_{PS}	Energy consumption of the secondary industry	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
E_{PT}	Energy consumption of tertiary industry	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
S_i	Proportion of output value of three industries	Data sourced from the statistical yearbook (2010–2019), and the follow-up is the forecast data
I_i	Energy consumption intensity of the three industries	Ratio of industrial energy consumption to industrial added value
E_{UR}	Urban energy consumption	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
E_{RR}	Rural energy consumption	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
e_{UR}	Urban energy consumption per capita	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
e_{RR}	Rural energy consumption per capita	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
I_{U}	Urban disposable income	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
I_{R}	Rural disposable income	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
R_{U}	Population urbanization rate	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
CI_{GDP}	Carbon intensity	Ratio of fossil energy carbon content to gross domestic product
EF_{E}	Energy carbon emission factor	Calculated according to different energy sources
$E_{s,i}$	Percentage of different energies	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data
ef_i	Carbon factors of different energies	Data sourced from the statistical yearbook (2010–2019), and the follow-up is forecast data

$$EI_{\mathrm{GDP}}=\frac{E}{\mathrm{GDP}}=\frac{E_{\mathrm{P}}+E_{\mathrm{R}}}{\mathrm{GDP}} \tag{1}$$

$$\frac{E_{\mathrm{P}}}{\mathrm{GDP}}=\frac{E_{\mathrm{PP}}+E_{\mathrm{PS}}+E_{\mathrm{PT}}}{\mathrm{GDP}}=\sum_{i=1\sim 3}(S_i\,I_i) \tag{2}$$

$$\frac{E_{\mathrm{R}}}{\mathrm{GDP}}=\frac{E_{\mathrm{UR}}+E_{\mathrm{RR}}}{\mathrm{GDP}}=\frac{e_{\mathrm{UR}}}{I_{\mathrm{U}}}\times\frac{I_{\mathrm{U}}}{\mathrm{GDP}}\times R_{\mathrm{U}}+\frac{e_{\mathrm{RR}}}{I_{\mathrm{R}}}\times\frac{I_{\mathrm{R}}}{\mathrm{GDP}}\times(1-R_{\mathrm{U}}) \tag{3}$$

$$CI_{\mathrm{GDP}}=\frac{\mathrm{CO_2\ emissions}}{\mathrm{GDP}}=\frac{E}{\mathrm{GDP}}\times\frac{\mathrm{CO_2\ emissions}}{E}=EI_{\mathrm{GDP}}\times EF_{\mathrm{E}} \tag{4}$$

$$EF_{\mathrm{E}}=\sum_i(E_{\mathrm{s},i}ef_i) \tag{5}$$

2.2 Modeling basic parameter settings

The basic parameters of the energy demand forecast include: gross domestic product (GDP), per capita GDP, industrial structure, industrial energy consumption intensity, urbanization processes, and other indicators from 2010 to 2019, and the forecast time period is 2020–2035, where the driving factors of the model are GDP, population size, industrial structure, energy efficiency, urbanization, living energy, and per capita income. The basic parameters of the model include population, secondary and tertiary industry structures, energy consumption intensity of secondary industry, urbanization rate, GDP growth rate, and per capita GDP (Table 2). The model is constrained by several aspects: (1) The permanent populations of the five central provinces before 2035 are predicted according to current population growth (from the sixth national census), based on the total fertility rate of the five central provinces from 2010 to 2018, and considering the “two child” policy factors. These were predicted using the Population Administration and Decision Information System of International Version population prediction software, where the total fertility rates of the Henan, Anhui, Hubei, Hunan, and Jiangxi provinces are 1.9, 1.8, 1.75, 1.85, and 1.85 respectively. (2) The second and third industrial structure parameters were extrapolated according to the law of industrial structure development of each province from 2010 to 2018. (3) The energy consumption intensities of the three industries were extrapolated based on the change law of industrial energy consumption, from 2010 to 2018. (4) The urbanization rate was derived from the urbanization policies and laws of each province from 2010 to 2018 and was combined with the urbanization laws of developed countries. (5) The GDP growth rate was extrapolated according to trends in the GDP growth rate of each province from 2010 to 2018. (6) GDP per capita is obtained by multiplying 2005 (as the base period) by the product of GDP growth rate and dividing by the total population.

3 Designing an energy demand scenario for the Rise of Central China Plan

3.1 Industrial structure and energy consumption scenario design

Industrial structure optimization was set as the benchmark and acceleration scenarios based on the development trends in the economic, social, and ecological dimensions of the central regions from 2010 to 2018, and considering the driving factors affecting the future energy demand of the central regions (Table 3). The benchmark scenario is mainly an extension of historical trends in each province, while the acceleration scenario assumes the implementation of an additional market-oriented mechanism in the future energy revolution. The energy revolution promotes the upgrading of industrial structure; this is the focus of regional economic development or industrial structure to transition from primary industry to secondary and tertiary industries, reflecting the level, stage, and direction of regional economic development.

3.2 Urbanization process and the scenario design of urban and rural energy consumption

In 2019, the rate of urbanization in China was 60.6%, where urbanization had entered the middle and late stages; it was estimated that this level of urbanization would reach 70% by 2030 and enter a later stage of development, where the development rate would decrease [15]. Among the five central provinces, only Hubei had an urbanization level slightly higher than the national average (61%), while the levels of other provinces were lower than the national average by varying degrees. There were also differences in the rate of urbanization in various provinces; for example, the corresponding values for the Henan, Anhui, Hubei, Hunan, and Jiangxi provinces were 1.55%, 1.19%, 1.0%, 1.4%, and 1.4%, respectively. In this context, this study set three urbanization scenarios with intervals of 0.1%.

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Table 2. Basic parameter settings for the rise of Central China (2020–2035).

Province	Year	Population (10 000)	Ratio of secondary to tertiary industries (%)	Change in intensity of energy consumption of secondary industry (%)	Rate of urbanization (%)	GDP growth rate (%)	Per capita GDP (10 000 CNY)
Henan	2020	9710	43.7:48.3	−5.3	53.33	7.0	4.9
	2025	9768	38.7:55.1	−4.8	57.45	6.1	6.6
	2030	9710	35.5:59.9	−4.3	61.73	5.5	8.8
	2035	9579	32.5:63.8	−3.8	66.18	5.0	11.5
Anhui	2019	6285	43.6:48.3	−5.2	56.01	7.2	3.9
	2025	6320	38.0:55.6	−4.7	59.31	6.0	5.3
	2030	6286	34.4:60.4	−4.2	62.64	5.1	7.0
	2035	6201	32.2:63.4	−3.7	66.00	4.4	9.1
Hubei	2020	5979	41.3:50.5	−5.0	61.51	6.7	5.3
	2025	6023	36.9:56.6	−4.5	64.49	5.3	7.0
	2030	5990	32.9:62.0	−4.0	67.44	4.4	8.8
	2035	5909	30.3:65.6	−3.5	70.36	3.6	10.8
Hunan	2020	6861	37.8:54.5	−3.2	57.60	7.0	4.6
	2025	6908	33.9:60.2	−2.7	61.59	6.1	6.1
	2030	6878	31.5:63.9	−2.2	65.70	5.5	7.8
	2035	6785	30.2:66.3	−1.7	69.91	5.0	9.7
Jiangxi	2020	4693	44.5:47.9	−4.9	57.58	7.8	4.1
	2025	4724	39.6:54.7	−4.4	61.57	6.9	5.8
	2030	4717	35.2:60.4	−3.9	65.68	6.2	8.0
	2035	4654	31.3:65.4	−3.4	69.89	5.7	10.8

Note: Data were calculated using the statistical yearbook data of the five central provinces over the target years; negative values signify a decrease.

Table 3. Forecast of energy intensity changes in the three industries of the five central provinces (2020–2035).

Province	Year	Annual rate of decline in energy consumption for the primary industry (%)		Annual rate of decline in energy consumption for the secondary industry (%)		Annual rate of decline in energy consumption for the tertiary industry (%)	
		Benchmark scenario	Acceleration scenario	Benchmark scenario	Acceleration scenario	Benchmark scenario	Acceleration scenario
Henan	2018–2020	2.2	1.7	−5.3	−5.8	−5.7	−6.2
	2021–2025	1.7	1.2	−4.8	−5.3	−5.2	−5.7
	2026–2030	1.2	0.7	−4.3	−4.8	−4.7	−5.2
	2031–2035	0.7	0.2	−3.8	−4.3	−4.2	−4.7
Anhui	2019–2020	5.5	5.0	−5.2	−5.5	−1.9	−2.0
	2021–2025	4.5	4.0	−4.7	−5.0	−1.8	−1.9
	2026–2030	3.5	3.0	−4.2	−4.5	−1.7	−1.8
	2031–2035	2.5	2.0	−3.7	−4	−1.6	−1.7
Hubei	2018–2020	3.4	2.9	−5.0	−5.5	−4.3	−4.8
	2021–2025	2.9	2.4	−4.5	−5.0	−3.8	−4.3
	2026–2030	2.4	1.9	−4.0	−4.5	−3.3	−3.8
	2031–2035	1.9	1.4	−3.5	−4.0	−2.8	−3.3
Hunan	2018–2020	1.5	1.0	−3.2	−3.7	−6.5	−7.0
	2021–2025	1.0	0.5	−2.7	−3.2	−6.0	−6.5
	2026–2030	0.5	0.1	−2.2	−2.7	−5.5	−6.0
	2031–2035	0.1	0.1	−1.7	−2.2	−5.0	−5.5
Jiangxi	2018–2020	2.2	2.7	−4.9	−5.4	−4.6	−5.1
	2021–2025	1.7	2.2	−4.4	−4.9	−4.1	−4.6
	2026–2030	1.2	1.7	−3.9	−4.4	−3.6	−4.1
	2031–2035	0.7	1.2	−3.4	−3.9	−3.1	−3.6

We also emphasized the coordinated development of the central regions, focusing on promoting the coordinated development of both urban and rural areas. Although the urban–rural income gap ratio of Henan, Anhui, Hubei, Hunan, and Jiangxi provinces decreased from 3.02, 3.21, 3.03, 3.05, and 2.64 in 2005, to 1.52, 2.46, 2.30, 2.30, and 2.34 in 2018, respectively, data from the International Labor Organization (2012) shows that in most countries, the urban–rural income gap ratio is approximately only 1.5 [16]. In Central China, only the Henan Province is close to this ratio, while Anhui Province has the highest ratio for the urban–rural income gap, and this ratio is mid-range in the Hunan, Hubei, and Jiangxi provinces.

The rise of Central China is a process that ultimately seeks to narrow the income gap between urban and rural areas, with several key manifestations. With the advancement of industrialization and urbanization, the proportion of the urban population in the five aforementioned provinces of Central China will gradually increase, and the income level will also increase accordingly. By 2035, modernization will be realized; during this process, the per capita income level will transition from middle- to high-income groups. Alongside this transition, Central China needs to narrow the income gap between urban and rural areas. Therefore, in setting the income elasticity of rural residents, the growth rate of their disposable income will be higher than that of urban residents. Under this assumption, the high, low, and benchmark scenarios of the income elasticity coefficient were developed. The coefficient was assumed to be at a level of one or higher near the transition point. Table 4 shows the three alternatives in terms of residents' incomes for comparative analysis.

Table 4. Forecast scenarios of the income elasticity coefficient in the five target provinces of Central China (2020–2035).

Province	Year	Elasticity coefficient of urban disposable income per capita			Coefficient of elasticity of the per capita net income of farmers		
		High growth scene	Benchmark scene	Low growth scene	High growth scene	Benchmark scene	Low growth scene
Henan	2020–2025	0.92	0.87	0.82	1.01	0.96	0.91
	2025–2030	0.97	0.92	0.87	1.02	0.97	0.92
	2030–2035	1.02	0.97	0.92	1.07	1.02	0.97
Anhui	2020–2025	0.90	0.85	0.80	0.97	0.92	0.85
	2025–2030	0.95	0.90	0.85	1.02	0.97	0.92
	2030–2035	1.00	0.95	0.90	1.05	1.02	0.97
Hubei	2020–2025	1.13	1.08	1.03	1.15	1.10	1.05
	2025–2030	1.15	1.10	1.05	1.17	1.12	1.07
	2030–2035	1.17	1.12	1.07	1.19	1.14	1.09
Hunan	2020–2025	1.01	0.96	0.91	1.04	0.99	0.94
	2025–2030	1.06	1.01	0.96	1.09	1.04	0.99
	2030–2035	1.11	1.06	1.01	1.14	1.09	1.04
Jiangxi	2020–2025	1.01	0.96	0.91	1.04	0.99	0.94
	2025–2030	1.06	1.01	0.96	1.09	1.04	0.99
	2030–2035	1.11	1.06	1.01	1.14	1.09	1.04

The growth of economic development and per capita income, the popularization of improved living conditions and household appliances, and the level of energy consumption in the daily lives of residents occurs concurrently. From international experiences in the Organization for Economic Co-operation and Development countries, the average household energy consumption accounts for 19% of the total energy consumption (excluding private transportation energy consumption) [17]. It is thus reasonable to expect that domestic energy consumption in the central regions will continue to increase. After 2020, the per capita domestic energy consumption in the five central provinces will likely increase in quantity and quality.

We set the elastic coefficient of urban and rural energy consumption in the five central provinces based on the development laws of Shanghai and other first-tier cities. This was established to reflect the rise of the central regions and narrow its gap with the eastern regions. Shanghai was selected as the reference benchmark because it

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has led the transition from middle- to high-income levels; the city can be used as a reference for the urbanization of energy consumption in central provinces. Specifically, in terms of per capita GDP, the value for Shanghai increased from 6138 USD in 2005 to 18 756 USD in 2017; the current per capita income of the five central provinces is within this range. The energy consumption elasticity of Shanghai varied from low to high and then back to low, and this turning point occurred in 2011; such relevant trends were also observed in Beijing, Shenzhen, and other first-tier cities [17]. In terms of the elasticity coefficient of energy consumption for rural residents, since the absolute level of energy consumption in the five central provinces was still low, the potential increase in energy demand was estimated to be larger with the increase in income. This assumes that the coefficient is initially one and that the income gap between urban and rural areas will gradually decrease over time. Table 5 presents the elastic predictions related to the consumption of living energy for the comparative analysis.

Table 5. Prediction of energy consumption elasticity in five provinces of Central China (2020–2035).

Province	Year	Urban areas		Rural areas	
		Baseline scenario	Acceleration scenario	Baseline scenario	Acceleration scenario
Henan	2020–2025	0.66	0.56	0.73	0.63
	2025–2030	0.56	0.46	0.63	0.53
	2030–2035	0.46	0.36	0.53	0.43
Anhui	2020–2025	0.92	0.82	0.96	0.94
	2025–2030	0.82	0.80	0.86	0.84
	2030–2035	0.72	0.62	0.76	0.74
Hubei	2020–2025	0.62	0.52	0.72	0.62
	2025–2030	0.52	0.42	0.62	0.52
	2030–2035	0.76	0.66	0.52	0.42
Hunan	2020–2025	0.6	0.55	0.74	0.64
	2025–2030	0.55	0.50	0.64	0.54
	2030–2035	0.5	0.45	0.54	0.44
Jiangxi	2020–2025	0.70	0.65	0.67	0.62
	2025–2030	0.65	0.60	0.62	0.57
	2030–2035	0.6	0.55	0.57	0.52

3.3 Designing a scenario on an energy revolution that enhances energy structure transformation

The fundamental core of the energy revolution is the development of clean and low-carbon energy, which changes the energy structure in terms of energy consumption. The energy consumption structure of the five central provinces is dominated by coal, and coal consumption accounts for a high proportion of their total energy use. In recent years, technological innovation has driven a downward trend in the proportion of direct coal consumption, and the clean conversion rate of coal has greatly improved. All provinces have invested significant efforts to develop renewable energy sources such as wind, light, water, and biomass. Ultimately, these combined energies form a multi-energy system, such as complementary wind–solar and water–solar systems. The West to East Gas Transmission, West to East Power Transmission, North to South Coal Transportation, and ultra-high voltage smart grids within regional energy cooperation establish the conditions required to transform the energy structure in Central China. This was utilized to construct an energy revolution scenario that promoted the transformation of the energy structure in Central China (Table 6).

Based on existing literature [18], there are 144 energy consumption scenarios with different rising paths under the given variables and assumptions. To summarize these scenarios and set three main scenarios according to the high, medium, and low GDP growth rates, we selected four key sub-scenarios under the GDP growth rate benchmark, high GDP growth rate scenario, and low GDP growth rate scenario. Table 7 presents an overall description of the energy demand scenarios under different rising paths.

Table 6. Primary energy structure scenarios of five provinces in Central China (2020–2035).

Province	Year	Baseline development scenario (%)				Energy revolution scenario (%)			
		Coal	Oil	Natural gas	Renewable energy	Coal	Oil	Natural gas	Renewable energy
Henan	2020	68.3	15.9	6.8	9.0	68.0	15.9	6.8	9.3
	2025	57.7	19.5	8.5	14.2	57.4	19.5	8.5	14.5
	2030	48.7	20.7	10.6	20.0	48.4	20.7	10.6	20.3
	2035	41.4	21.3	13.4	23.9	40.9	21.3	13.4	24.4
Anhui	2020	70.5	18	5.2	6.3	70	18	5.2	6.8
	2025	66.4	18.2	8.1	7.3	63.8	18.2	8.1	9.9
	2030	61.3	18.4	9.3	11	58	18.4	9.3	14.3
	2035	56	18.6	10.1	15.3	53.3	18.6	10.1	18
Hubei	2020	47.3	21.7	5.4	25.6	47.0	21.7	5.4	25.9
	2025	43.4	21.9	8.8	25.9	43.1	21.9	8.8	26.2
	2030	37.4	22.2	14.2	26.2	37.1	22.2	14.2	26.5
	2035	32.5	22.5	18.5	26.5	32.2	22.5	18.5	26.8
Hunan	2020	63.7	16.4	3.0	16.9	63.4	16.4	3.0	17.2
	2025	60.3	16.6	4.8	18.3	60.0	16.6	4.8	18.6
	2030	55.6	16.9	7.8	19.7	55.3	16.9	7.8	20.0
	2035	51.8	17.1	10.1	21.0	51.5	17.1	10.1	21.3
Jiangxi	2020	68.8	18.2	4.1	8.8	68.5	18.2	4.1	9.1
	2025	63.1	18.5	6.7	11.7	62.8	18.5	6.7	12.0
	2030	53.4	18.7	10.8	17.1	53.1	18.7	10.8	17.4
	2035	44.6	19.0	14.0	22.4	44.3	19.0	14.0	22.7

Table 7. Overall description of the optimization of the industrial structure and the setting of urbanization scenarios for the rise of Central China.

Scene	Type	SE11	SE12	SE13	SE14	SE21	SE22	SE23	SE24	SE25	SE31	SE32	SE33	SE34
GDP	High growth	√	√	√	√									
	Benchmark					√	√	√	√	√				
	Low growth										√	√	√	√
Industrial structure	Acceleration	√	√					√	√				√	√
	Benchmark			√	√	√	√			√	√	√		
Urbanization	High growth	√	√	√	√					√				
	Benchmark					√	√	√	√					
	Low growth										√	√	√	√
Energy efficiency	Acceleration	√		√			√		√			√		√
	Benchmark		√		√	√		√		√	√		√	
Per capita income	High growth	√	√	√	√					√				
	Benchmark					√	√	√	√					
	Low growth										√	√	√	√
Living energy	High growth	√	√	√	√					√				
	Benchmark					√	√	√	√		√	√	√	√

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4 Energy revolution pathway that enhances the rise of Central China

4.1 Energy demand in different paths for the rise of Central China

Various macro factors during the rise of the central region, such as economic growth, industrial development, new urbanization, energy efficiency, per capita income, and lifestyle energy needs, were integrated into different development paths. These development paths and their corresponding effects were obtained through the guidance and implementation of relavent policies. According to the various scenarios of the five central provinces, we acquired energy demand from each province in different pathways, from 2020 to 2035.

Using the high economic growth scenario as an example (Fig. 2), the rising energy demand in the central region should increase by 2035, with no turning point. The energy demand will be approximately 8.45×10^8 to 1.0×10^9 tce; if the energy revolution is adopted to promote the optimization of the industrial structure and improve energy efficiency (SE11 path), the energy demand by 2035 will be 9.12×10^8 tce. If the energy revolution cannot promote the optimization of the industrial structure and improve energy efficiency, and there will be accelerated urbanization (SE14 path) and the energy demand will be approximately 1.0×10^9 tce. The SE12 or SE13 paths promote upgrades to the industrial structure and improve energy efficiency; however, the energy demand of the SE13 path is 4.55×10^7 tce lower than that of the SE12 path. This shows that improvements in energy technology efficiency have a greater impact than industrial structure optimization

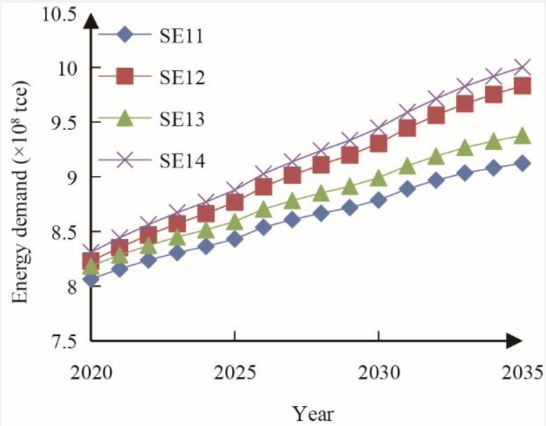

Fig. 2. High-growth economic energy demand (2020–2035).

Against the backdrop of benchmark economic growth, the energy demand of the five central provinces will be approximately 9.01×10^8–9.74×10^8 tce by 2035. With upgrades to the industrial structure and improvements to energy efficiency (SE24 path), the energy demand of Central China will be 9.01×10^8 tce. If the energy revolution cannot promote upgrades to the industrial structure and improve energy efficiency, the energy demand will be 9.74×10^8 tce, and the energy demand for the other pathways will be between these two values. In the energy revolution, if the industrial structure is adjusted and the energy efficiency is improved concurrently (SE22 path), the energy demand will be 9.11×10^8 tce. If only the industrial structure is upgraded and energy efficiency is not improved (SE23 path), the energy demand will be 9.60×10^8 tce. In terms of accelerating urbanization, the industrial structure and energy efficiency remain unchanged (SE25 path), and the energy demand will be 9.58×10^8 tce.

Against the backdrop of low economic growth, the energy demand can be divided into four situations by 2035. First, in the benchmark scenario (SE31 path), the energy demand will be 9.11×10^8 tce. Second, in the benchmark scenario where the energy revolution improves energy efficiency (SE32 path), the energy demand will be 8.57×10^8 tce. Third, in the SE32 path, where the energy revolution accelerates optimization and upgrades to the industrial structure (SE33 path), the energy demand will be 8.99×10^8 tce. Lastly, the SE33 path and energy revolution promote the optimization of the industrial structure and improve energy efficiency; in this situation, the energy demand will be 8.45×10^8 tce.

Thus, during the process of promoting the rise of the central regions, the energy revolution plays a crucial role in optimizing the industrial structure and improving energy efficiency. On the one hand, it reduces energy consumption, that is, the energy consumption revolution, while on the other hand, it provides a pathway for the rise of central regions.

4.2 Path of the CO_2 emissions inflection point in the rise of Central China

A key part of the energy revolution is to promote energy transformation, which means developing toward a clean, low-carbon direction by optimizing the energy structure. Based on the various rising path assumptions, together with the energy revolution and benchmark energy supply scenario assumptions, there are 432 CO_2 emission scenario combinations of different rising paths. We determined the inflection point year of the energy carbon emission peak by summarizing these scenarios and combining economic benchmark growth, high economic growth, and low economic growth with the energy revolution and energy benchmark development scenarios.

Similarly, using high economic growth as an example, if the energy in the central region develops according to the benchmark scenario (Fig. 3), the CO_2 emissions of the central regions under the four different rising paths will peak at 2022 and decelerate beyond 2022. Compared with the benchmark and energy revolution scenarios (SE11, SE13 path), the peak year of CO_2 emissions is 2020; however, under the energy revolution scenario (Fig. 4), total emissions are lower. For SE12 and SE14, the peak year under the benchmark scenario was 2022, and the peak year under the energy revolution scenario was 2021, while the total emissions under this scenario were lower.

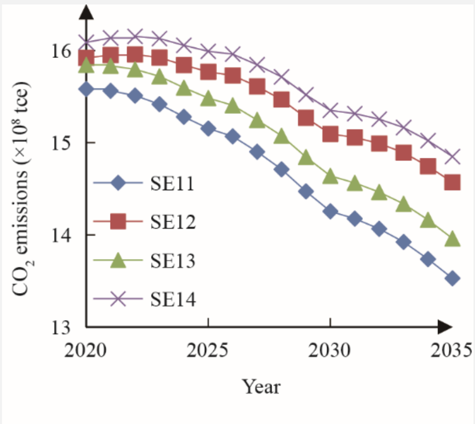

Fig. 3. High economic growth + energy benchmark CO_2 emissions (2020–2035).

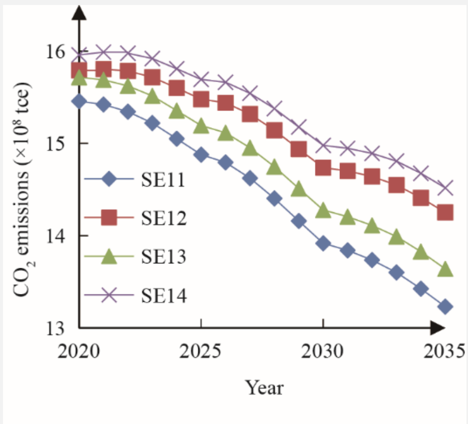

Fig. 4. High economic growth + energy revolution CO_2 emissions (2020–2035).

Considering economic benchmark growth, if the energy demand in central regions develops according to the benchmark scenario, peak CO_2 emissions under five different rising paths will occur in 2021. Emissions would then decrease annually with the transformation of the energy structure. In terms of carbon emissions, the energy revolution scenario will be 1.434×10^7–1.474×10^7 tce lower than the benchmark energy structure.

Considering low economic growth, if the energy demand in the central region develops according to the benchmark scenario, peak CO_2 emissions under the four different rising paths will occur in 2021. It then decreases each year through the transformation of the energy structure. Similarly, the energy revolution will significantly

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reduce CO_2 emissions, which is conducive to the mitigation of global climate change and improvements to the regional environment.

Thus, the combination of the energy revolution and the rise of central region strategies will promote high-quality development of the central region, i.e., energy revolution promotes the transformation and upgradation of the industrial structure in central regions by changing the energy structure and improving energy efficiency; it also plays a positive role in the development of new urbanization and the improvement of living standards for residents.

5 Countermeasures and suggestions

The results show that the energy demand of Central China will continue to rise with industrialization and urbanization, based on economic growth, industrial development, urbanization, and existing energy-saving policies. No turning point will occur prior to 2035, although improvements in energy efficiency and the optimization of industrial structures will help to reduce energy demand. The energy revolution, aimed at building a multi-complementary energy system, will help Central China rapidly reach a CO_2 emission peak and promote the coordinated development of the economy, society, and the environment in the central region. This paper recommends specific developments for the regional energy revolution in response to the contextual rise of the central region.

5.1 Development of energy-saving and clean technology, improving energy efficiency, and clean, low-carbon energy supply

Coal is the main energy source in Central China, and the dominance of coal in primary energy is difficult to modify in the short term. As thermal power is the main method of coal conversion in China, innovation in thermal power technology is important since it relates to clean technology. The clean utilization of coal is the future focus of the energy revolution; energy conservation and efficiency improvement are the first tasks in China's energy strategy [19]. However, there is a need to strengthen upgrades to thermal power units, eliminate small-scale units in central regions, regulate the energy input-output efficiency of various industries in the region, and continuously improve energy utilization efficiency. Planning and implementing the development of renewable energy sources such as hydropower, wind power, photovoltaics, and bioenergy is also important.

5.2 Strengthening the adjustment of industrial structures and shift to green and low-carbon energy

The energy revolution promotes the rise of Central China—this not only reflects issues with the energy industrial structure itself but is also reflective of the rapid and ecological development of the entire industrial structure in the region. Under the new concept of ecological priority and green development, central regions should alter the mode of traditional extensive development that relies on resources, and instead focus on industrial transformation and upgradation, taking actions that suit local circumstances to promote adjustments in the industrial structure, and developing a low-carbon and environmentally friendly pathway. It is suggested that the ecological concept should be included in the industrial transformation and upgradation process, and new industrialization should be developed to adjust and optimize industrial structure. The industrial mode of resource–product–waste discharge should be modified to develop an ecological civilization that achieves a harmonious coexistence between man and nature. Advanced technologies should be adopted to upgrade traditional industries, implement traditional process upgrades, and utilize information technology and new energy technology to promote industrial ecological development.

5.3 Promoting energy system reform and establishing a competitive multi-energy market

The development and growth of new energy are inseparable from market breakthroughs. The current operation of the coal power pool and coal power integration in China has enabled coal power to monopolize the power grid. In contrast, the price of wind energy, photovoltaics, and other renewable energy sources can compete with that of traditional thermal power. To enable complete utilization of the decentralized characteristics of renewable energy, matching with the engineering construction of beautiful countryside and safe communities, China should adopt a development pathway from rural to urban, from living to production, design a competitive market, and facilitate the decisive role of the market in resource allocation. In light of regional differences in the distribution of wind and solar energies, provinces in central regions should build a consultation mechanism, break administrative division, and strengthen regional cooperation in the use of renewable energy. They should also promote the reform of energy systems, break institutional constraints and the regional gap, advocate the prioritization of development and utilization of renewable energy, and better implement the concept of ecological priority development.

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